Name:

*Project: ‘TOM: Teaching flow Over Mountains’*
Deadline 29 April 2011, 2pm; 62 points

**Concept of orographic precipitation:**

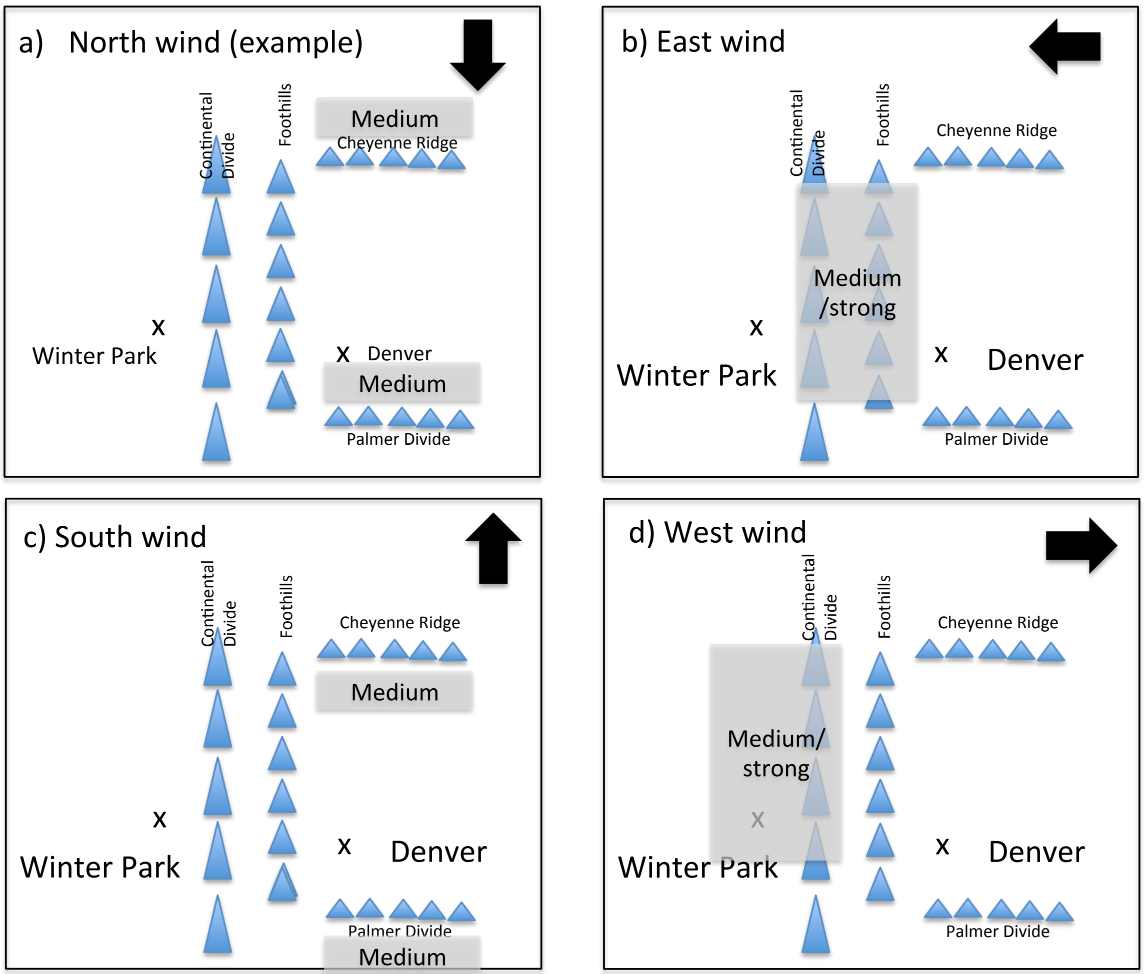



*Figure 1: Schematic illustrating topography around Denver (blue mountains) and the dominant wind flow (thick black arrows).*

1) Use the Figure 1 to answer the following questions. **(8 points)**
   a. Highlight the regions in Figure 1b, c, and d where you would expect precipitation (rain or snow) to occur. An example of the precipitation distribution for a northerly wind across the entire region is shown in Fig. 1a.

   b. Indicate in Fig. 1b, 1c, and 1d if you would expect high or low precipitation amounts and explain why.

c. List other meteorological parameters (beside wind) that determine the intensity of the precipitation.
Stability
Moisture

**Climatology:**

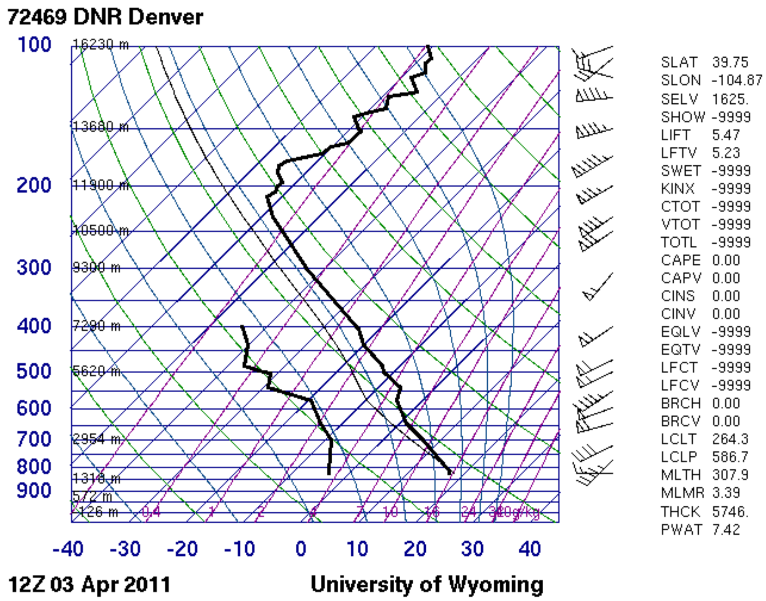
2) Go to the ATOC weather statistic site (http://foehn.colorado.edu/weather/paos1/monthly_stats.html), and complete the graph below showing the precipitation in March for 2006-2011. (**4 points**)


*Figure 2: Accumulated precipitation (in inches) in March 2006 and 2011.*

For the following questions use images and animations posted at
http://rain.colorado.edu/TOM-data

**Environmental conditions during TOM (3 April 2000 UTC - 4 April 0500 UTC):**

3) Use the Denver sounding on 3 April 12Z and 4 April 00Z to answer the following questions. (**6 points**)
   a. Describe the vertical profiles of temperature, moisture and wind at 12Z.




Temperature:

- 18deg @ surface, stable conditions between surface 600mb, inversion at 600-550mb,
- tropopause height at ~200mb

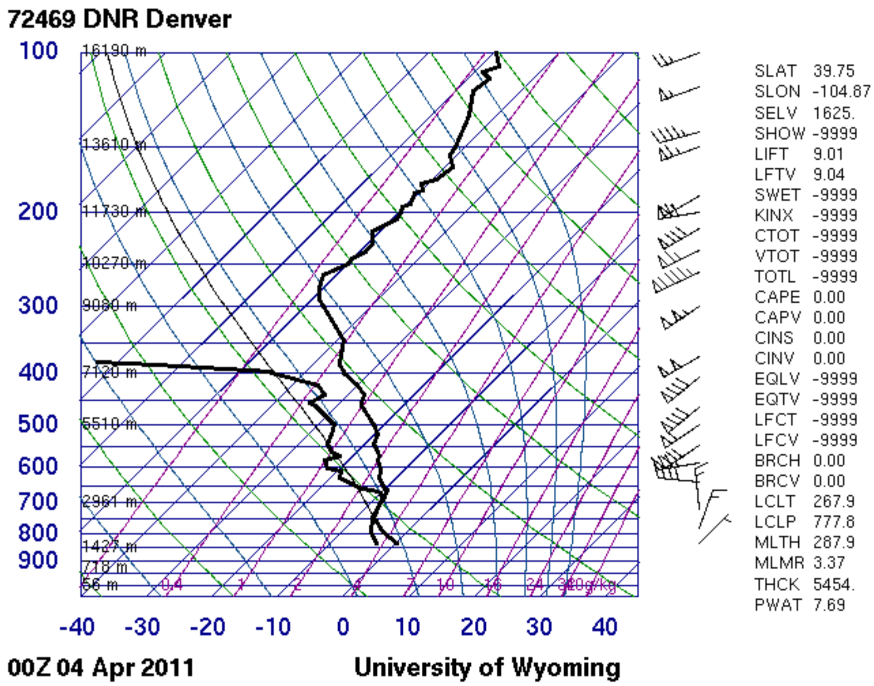
Moisture:

- very dry throughout the lower troposphere ~20deg spread at surface, i.e., relative humidity = 5.4mb( -2deg)/21.1mb(18deg) = 26%

Wind:

- W15 knots at surface turning to SW 60 knots at 500m

   b. Describe how the temperature, moisture and wind changed over 12 hours. Compare the vertical profiles of temperature, moisture and wind at 12 Z with observations at 00Z.




Temperature:

- Temperature decreased to 0deg @ surface, stability degreased but still stable conditions between surface 750mb, inversion between 750- 650mb,
- tropopause height at ~280mb

Moisture:

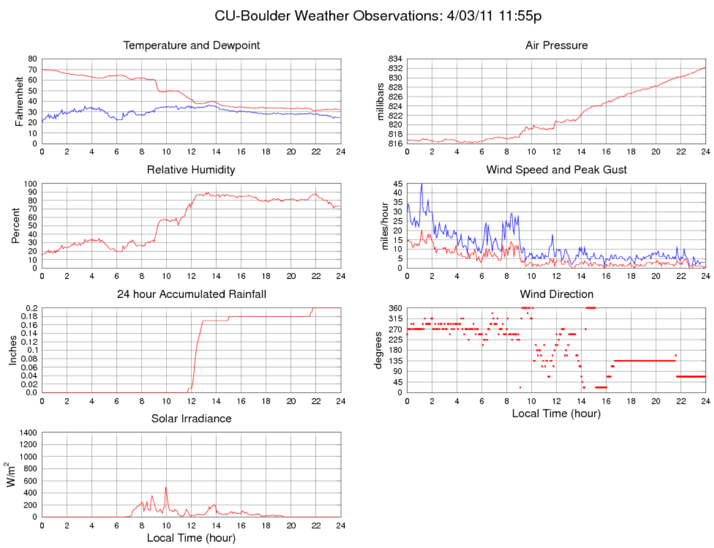
- moisture increased at the surface ~2deg spread at surface, i.e., relative humidity = 5.4mb( -2deg)/6.1mb(18deg) = 88%
- clouds between 750-650 mb RH~100%
- moisture also increased between 650-400 mb

Wind:

- NE 5 knots at surface up to 700 mb then SW-W 40-80 knots
- Upper-level jet at 300-400 mb

4) Choose a set of images showing surface observations (temperature, dew point, pressure, wind) which covers the time of the TOM experiment (3 April 2000 UTC – 4 April 0500 UTC). Please write down which station you used. (**6 points**)

   a. Describe the changes in temperature, moisture and wind before and during the snow storm.




Temperature:

- Temperature relatively warm in the morning 0am-9am LT => 60-70deg F
- Rapid decrease by 10deg F at 9am and 11am-12pm LT
- Temperature around freezing (32deg F) afternoon and evening after 2pm LT
- Dew point temperature remains the same, i.e., vapor pressure does not change
- Temperature decreases, i.e., saturation vapor pressure decreases and relative humidity increases

Moisture:

- Relatively dry in the morning until 9am LT (RH < 40%)
- Sudden increase in relative humidity at 9am and 11am-12pm to 90%
- RH stayed around 80-100% throughout the afternoon and evening (2pm LT p 12am LT)
- Rain started shortly before 12pm LT

Wind:

- Wind speeds > 5m/ until 9am LT; large wind gust during the night with up to 45 miles/hour
- Calm winds after 2pm (< 5 miles/hour)
- SW-westerly winds before 10am, wind SE between 4-10pm and NE after 10pm

b. Based on the surface observations can you identify a surface front? Describe the parameters that you use to identify the front and how they changed with time. At what time did the surface front passes the station?

- Cold front passed around 9am: temperature dropped, pressure increased, wind direction change between 9am-2pm but typical change (S to NW) not evident

**TOM Radar setup:**

5) Figure 3 shows topography and radar reflectivity measured by the rapid-scan DOW radar on 4 April at 0056 UTC. At the time the radar image was taken there was no precipitation in the area. The reflections you see on the radar image are all related to obstacles. Use the images and answer the following questions. (**17 points**)

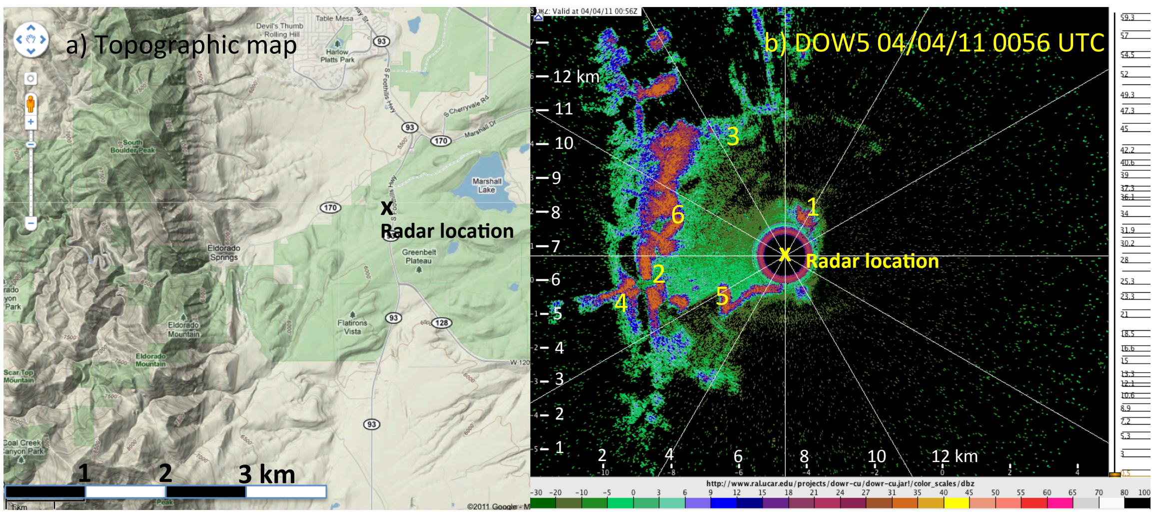
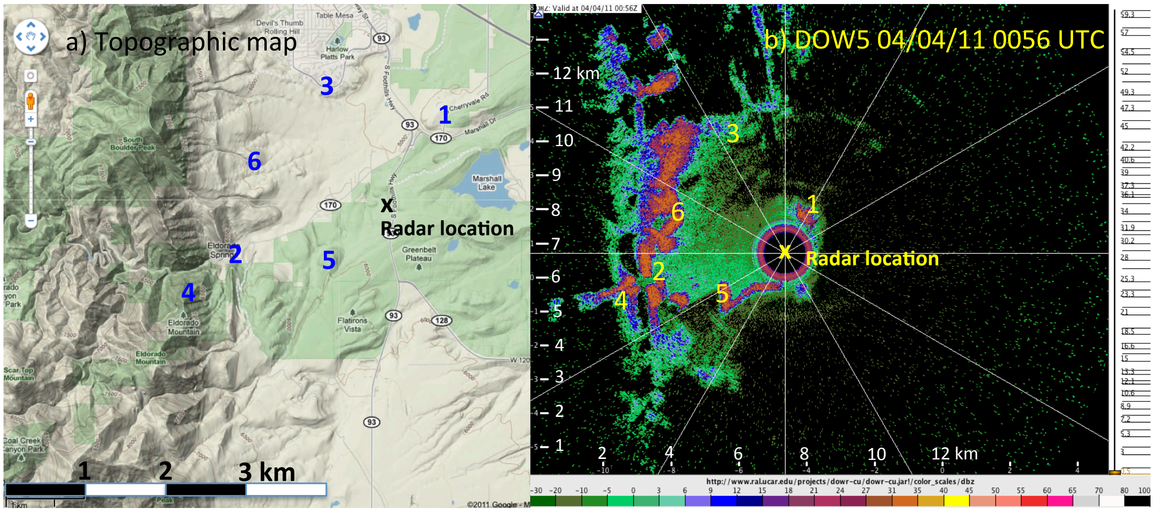



*Figure 3: a) Topographic map of south of Boulder near the rapid-scan DOW5 location and b) radar reflectivity (color-coded) measured by the rapid-scan DOW. The radar location is indicated by the x symbol.*

a. At what time (date and local time) was the image taken?
   **0056UTC, 656 pm LT**

b. Place the appropriate numbers shown in the radar image in Fig. 3b to the topographic features in Fig. 3a.




c. What is the distance between the radar and the mouth of Eldorado Canyon? The distances in km are indicated as white numbers on the bottom of a).

**2-3 km**

d. Most radars start scanning at 0.5 degrees elevation angle. However, with increasing distance from the radar, the radar beam will be located higher above the ground (Fig. 4b). Feature that occur close to the ground are often important for the evolution of severe weather but most radar cannot observe these feature because the radar beam is just too far away from the ground. The following exercise will show the differences. Use the trigonometric identities in Fig. 4a to calculate the height of the radar beam above ground level (see Opposite O in Fig. 4a).

   a. What is the height of the rapid-scan DOW radar beam at 0.5 degrees elevations (see Angle x in Fig. 4a) above ground at the mouth of Eldorado Canyon? Assume that the distance between the rapid scan DOW radar and the Canyon is 3 km (see Adjacent A in Fig. 4a; orange triangle in Fig. 4b).

   Answer:
   **1?** Rapid-scan Dow: The radar beam will be ___**0.03**________km above ground level (AGL) when scanning at 0.5 degree elevation angle.

   b. What is the height of the WSR-88D radar beam at 0.5 degrees elevations (see Angle x in Fig. 4a) above ground at the mouth of Eldorado Canyon? The distance between the WSR-88D Denver radar and the Canyon is 60 km (see Adjacent A in Fig. 4a; blue triangle in Fig. 4b).

   Answer:
   **2?** WSR-88D Denver: The radar beam will be ___**0.52**________km above ground level (AGL) when scanning at 0.5 degree elevation angle.

c. Use the height of the WSR-88D 0.5 deg elevation angle (2?) and determine the elevation angle. This time the Opposite (O) and Adjacent (A) are given,

d.

Answer:
**3?** Rapid-scan DOW: In order to scan up to 2?__**0.52**____ km AGL the rapid-scan DO W needs to have an elevation angle of ___**9.4**____degree.

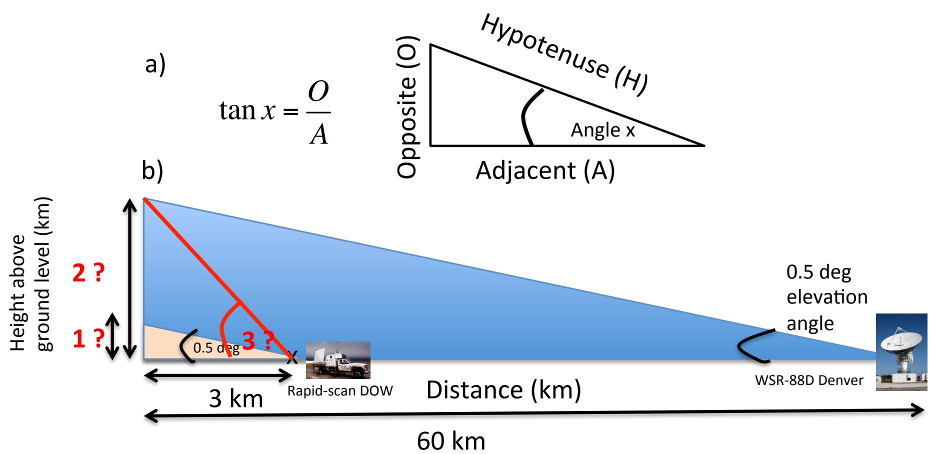
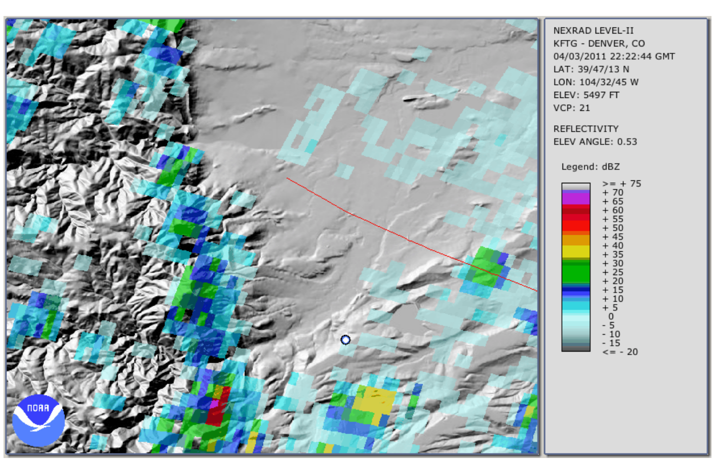



*Figure 4: a) Trigonometric identities and b) schematic of the problem.*

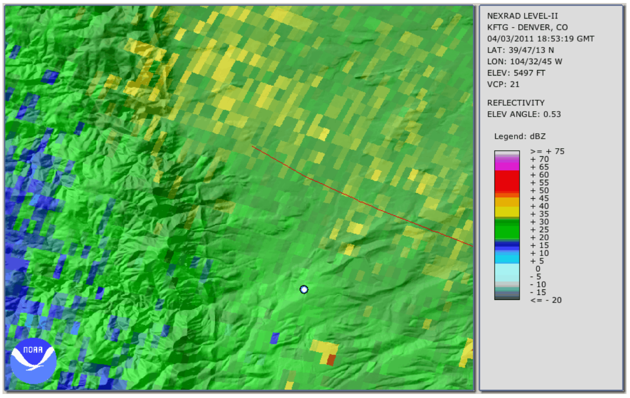
**TOM - Interpreting radar images**

6) To answer the following questions use the WSR-88D radar reflectivity loops at 0.5 degrees elevation (WSR-88D reflectivity zoom version) and rapid-scan DOW reflectivity loops at 4.1deg elevation (DOW reflectivity). (**21 points**)

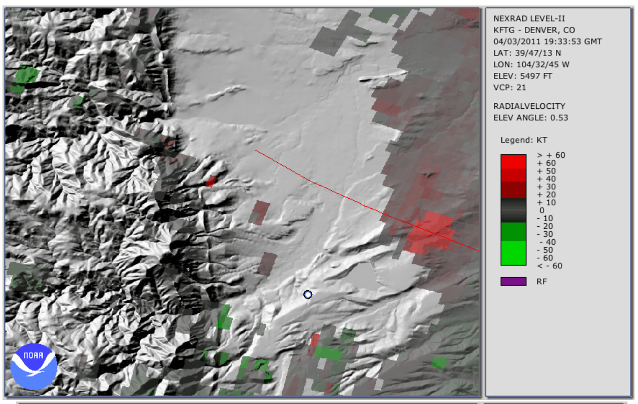
   a. How do the reflectivity and Doppler velocities measured in the snow differ from the reflectivity and the Doppler velocity from the mountains? Use the WSR-88D reflectivity and Doppler velocity data to answer this question (zoomed versions).



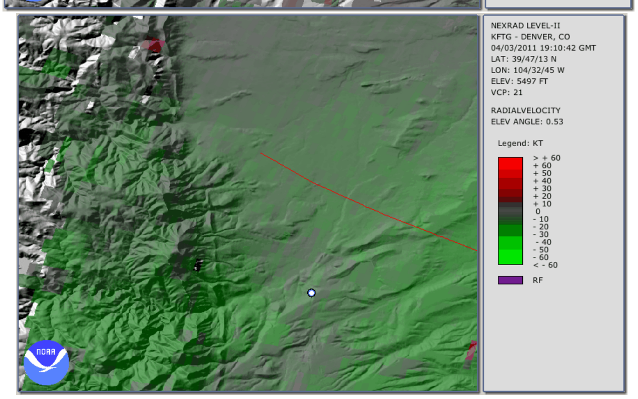

Higher reflectivity values are seen consistently (in every radar sweep) along the mountains at low elevation angles with values of ≥ 30 dBZ. Especially when no or hardly any precipitation is in the area the mountains still show reflectivity values (see image). Precipitation (snow/rain mix) has lower reflectivities ranging from 5-30 dBZ. Note that when




precipitation is over the mountains and has values of 30 dBZ (e.g., 1720 UTC) it is hard to distinguish between mountains and precipitation( see image).




If there is no precipitation in the area, mountains still create a reflection with zero velocities (see grey areas in image). When precipitation is in the area, mountains are hard to identify using Doppler velocities because the signal scattered back to the radar consist of precipitation (moving = velocity is not zero) plus mountains (stationary = velocity is zero).




b. Use the WSR-88D radar loops and read the reflectivity range of the precipitation that occur around the rapid-scan radar site. Make sure that you only consider reflections from rain or snow and NOT from the mountains.

| | **Begin/end time (UTC)** | **Reflectivity precipitation NWR-88D** |
|---|---|---|
| Event#1 | 1630-1900 UTC | 5-45 dBZ |
| Event#2 | 2030-2210 UTC | 0-15 dBZ |
| Event#3 | 2340-0124 UTC | 0-30 dBZ |
| Event#4 | 0320-0440 UTC | 0-35 dBZ |

| | | |
|---|---|---|

c. Describe differences between images taken by the NWR-88D and the rapid scan DOW during 0320-0440 UTC (spatial range, spatial and temporal resolution)? Can you identify features (enhance reflectivity line, no reflectivity) in one image that do not show up in the other, i.e., what do we see/what do we miss? Use the movies from the rapid-scan DOW at 6.3deg elevation angle.

| | **NWR-88D** | **DOW** |
|---|---|---|
| **Reflectivity range** | 0-35 dBZ | Mainly < 6 dBZ with some snow having up to 12 dBZ |
| **Spatial resolution** | Lower, reflectivity bands are wider | Higher, reflectivity bands are finer |
| | Reflectivity also west of mountains | Reflectivity mainly east of mountains |
| | Identify each pixel | Can hardly see pixel |
| **Temporal resolution** | Images every 5 min | Image every minute |
| **Mountains** | Lower reflectivity (30 dBZ) | High reflectivity (>45 dBZ) |